

Halo and Tail Generation Studies and Application to the CLIC Drive Beam



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Outline



- **Motivation**
- **Sources of halo and tail generation**
- **Challenges of the CLIC drive beam**
- **Results of the halo and tail generation studies for the CLIC drive beam**
 - **Analytical estimates**
 - **Tracking results**
- **Summary**
- **Outlook**

Motivation



- Halo particles can be a major source of **background** and **radiation**
 - Even if most of the Halo particles are stopped by collimators, the **secondary muon background** can still be significant
 - Halo and tail generation can lead to significant **beam losses** in all parts of an accelerator
- Halo and tail generation studies are needed for design studies to estimate and minimise any potential performance limitations from this source
- Halo and tail simulation with **PLACET-HTGEN**:



Sources of Halo and Tail Generation



Particle Processes:

- **Beam gas scattering** (Mott scattering and Bremsstrahlung) and **multiple scattering**
- Compton scattering
- Touschek effect and intrabeam scattering
- Electron and ion cloud effects
- Space charge effects
- **Synchrotron radiation**

Optics related effects:

- **Mismatch**
- **Coupling**
- **Dispersion**
- **Nonlinearities**

Various:

- Noise and vibrations
- Dark currents
- **Wakefields**
- **Spoiler scattering**



currently included in **PLACET-HTGEN**

Challenges of the CLIC drive beam



CLIC drive beam parameters

Parameter	Unit	Value
Drive beam sector length	m	1053
mean initial beam energy	GeV	2.40
mean final beam energy	GeV	0.40
numb. of part. per bunch	10^9	52.5
$\epsilon_{N,y,initial}$	μm	150
$\epsilon_{N,y,final}$	μm	334



Drive beam is a **low energy** and **high intensity** beam

HTGEN was written for high beam energies



Low energy validation of **PLACET-HTGEN**



Collective effects like wakefields become important



Implementation of the effect of transverse wakefields of the beam on the halo is needed for a realistic halo tracking



Results – Analytical estimates



Intrabeam Scattering and Touschek effect

are probably less important as the drive beam beam size is comparatively big

Electron and ion cloud effects

drive beam is a negatively charged beam



only ion cloud effects are important

decelerator is a linear “accelerator”



fast ion instability can occur, but the conventional ion instability is improbable

Some simple analytical estimates:

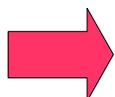
tune shift	
$\Delta\nu_{x,inc,initial}$	$5.26 \cdot 10^{-3}$
$\Delta\nu_{y,inc,initial}$	$1.29 \cdot 10^{-2}$
$\Delta\nu_{x,inc,final}$	$1.55 \cdot 10^{-2}$
$\Delta\nu_{y,inc,final}$	$3.51 \cdot 10^{-3}$
$[n_{rt,initial}, 3n_{rt,initial}]$	$[1.90647, 5.71940]$
$[n_{rt,final}, 3n_{rt,final}]$	$[0.51999, 1.55998]$

number of rise times

To ensure the beam stability, the tune shift, caused by the fast ion instability, and the number of rise times along the beam line should stay below one.



Fast ion instability could be relevant in the decelerator

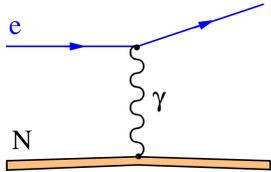


Extension of the fast ion simulation code (E. Adli, G. Rumolo, D. Schulte)

Results – Analytical estimates

Beam gas scattering and Compton scattering

Mott scattering

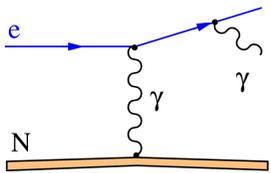


- elastic beam gas scattering
- more relevant for small beam energies

$$\sigma_{\text{Mott}}(\theta_{\text{min}}) = \pi \left(\frac{Zr_e}{\gamma} \right)^2 \left(\frac{1}{1 - \cos \theta_{\text{min}}} \right),$$

$\beta \rightarrow 1, \theta_{\text{min}} \geq \sqrt{\epsilon_N / (\gamma \beta_y)}$
beam divergence

Bremsstrahlung



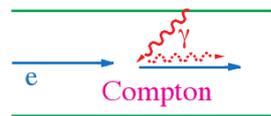
- inelastic beam gas scattering
- energy independent

$$\sigma_{\text{Brem}} = \frac{A}{N_A X_0} \left(-\frac{4}{3} \ln k_{\text{min}} - \frac{5}{6} + \frac{4}{3} k_{\text{min}} - \frac{k_{\text{min}}^2}{2} \right)$$

X_0 = Radiation length, A = Atomic mass number
 k = Photon energy in respect to the beam energy,

$$k_{\text{min}} \approx 0.01$$

Compton scattering



- scattering of thermal photons
- more relevant for high beam energies ($E'_\gamma = \gamma^2 \cdot E_\gamma$)
- mean free path length normally small for room temperature, but the caused energy spread can lead to significant losses (i.e. LEP)

scattering probability $P = n \cdot \sigma$
 density

Results – Analytical estimates



residual gas constitution: 40% H₂O, 40% H₂, 20 % (CO₂, CO and N₂)

Parameter	Unit	Value
temperature	K	300.0
pressure	nTorr	10.0
k_{\min} (Brem.)		0.01
θ_{\min} (Mott)	murad	96.9



Process	ρ [m ⁻³]	P_{init} [m ⁻¹]	P_{final} [m ⁻¹]
Mott	$3.22 \cdot 10^{14}$	$7.96 \cdot 10^{-12}$	$4.21 \cdot 10^{-11}$
Brems.	$3.22 \cdot 10^{14}$	$1.11 \cdot 10^{-13}$	$1.11 \cdot 10^{-13}$
Comp.	$5.45 \cdot 10^{14}$	$3.63 \cdot 10^{-14}$	$3.63 \cdot 10^{-14}$

scattering probability



Mott Scattering is the dominant process

energy spread caused by Compton scattering: $\Delta E/E \leq 0.25\%$

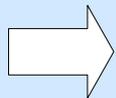


energy spread negligible compared to the energy spread caused by the deceleration of the beam

taking **Mott scattering**, **Bremsstrahlung** and **Compton scattering** into account, the total scattering probability integrated over the whole decelerator is:

$$P_{\text{tot}} = 7.69 \times 10^{-9}$$

$$\text{\#halo particles per bunch} = 2.67 \times 10^3$$



very small halo generation



Results – Tracking



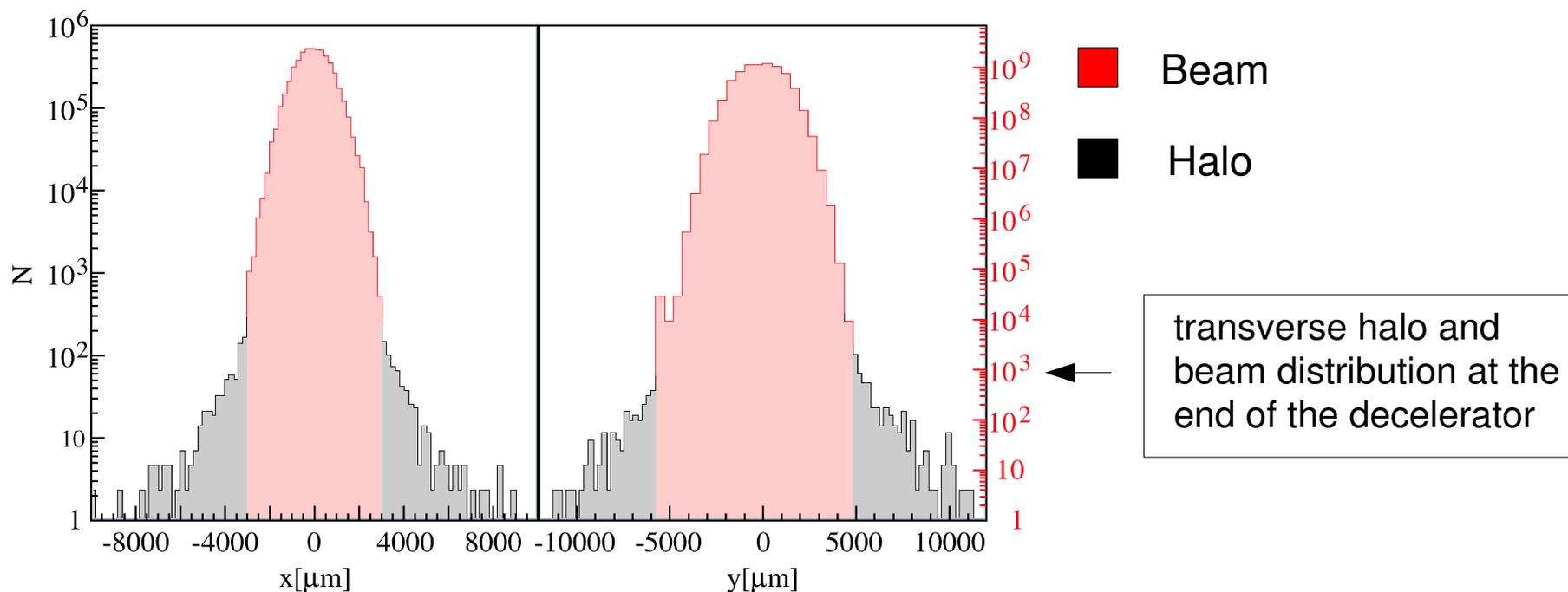
Model:

Strongest halo generation is expected for the **longest decelerator** (1053 m) for simplicity gas equivalent of N_2

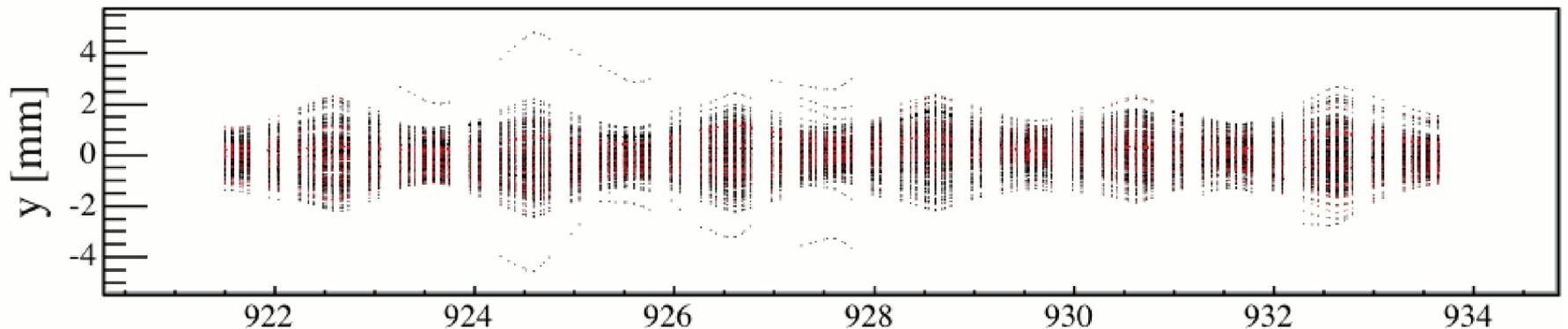
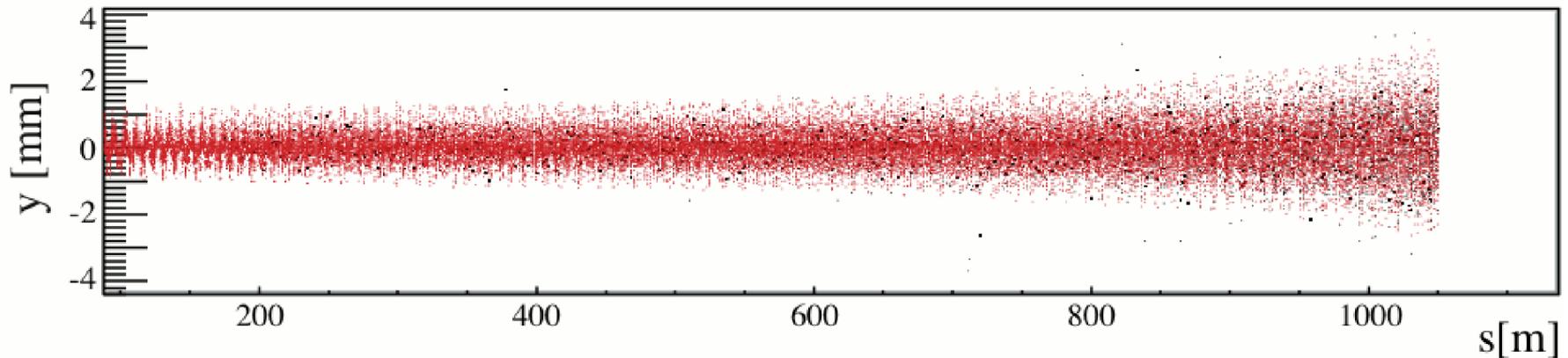
Beam: **sliced beam** model with a reduced number of bunches (200)

Halo: **particle beam** model

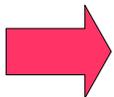
In tracking included: **offset** of the beam, **misalignment** of PETS and quadrupoles, **wakefield** effects



Results – Tracking



Beam and halo along the decelerator and an extract of the decelerator



- very small fraction of particles of 10^{-7} is lost (only halo losses)
- most of the lost particles are low energy particles with large scattering angles

Summary ...



- **Extension of PLACET-HTGEN to lower beam energies**
- **Implementation of halo tracking in the PETS including transverse wakefield effects**
- **Halo studies for the CLIC drive beam:**
 - **Analytical estimates indicate very small halo generation**
 - **Simulations predict very few losses**
 - **fast ion instability is not included in the present studies, but an extension of the Fast-Ion-Code is planned**

■ Touschek effect and Intrabeam Scattering

- total #intrabeam scattering events per unit time is prop. to $1/\beta^4$, $\beta = v/c$
- effect increases with the particle density
 - ⇒ more relevant for low energy beams with a small beamsize
- In the CLIC decelerator the Touschek effect could be more important than in comparable linear accelerators without decelerating sections, because beam particles, which have performed Touschek scattering and lost longitudinal momentum, could lose almost all their longitudinal momentum during the deceleration and get lost



- longitudinal losses in the decelerator?
- “simple” implementation of the Touschek effect in **HTGEN**?

■ Space charge effect

- becomes more relevant for small beam energies (i.e. could be relevant for the TBL)
- no studies of space charge effects for lattices including PETS?

... and Outlook



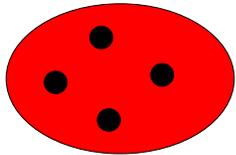
■ further halo and tail generation studies with **PLACET-HTGEN**

Implementation of halo tracking including wakefield effects is completed
(together with [Barbara Dalena](#))



Halo tracking now implemented for all present elements of CLIC

■ analyzer version of **PLACET-HTGEN**



- Test particle (defined as Halo particles)

- creation of test particles in specific elements (i.e. before the first element)
- test particle distribution is created out of an input file (6d particle coordinates)
- scattering of particles can be switched on and off

Thanks!



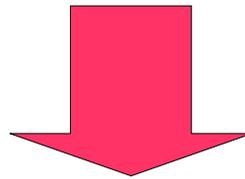
Backup Slides

Electron cloud effects



Sources of electron clouds:

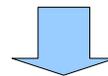
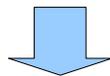
- **Ionization** of the restgas
- **Synchrotron radiation** photons knock out photo-electrons of the beampipe
- Electron hits the beampipe
→ **secondary emission** of electrons ...



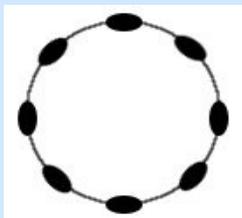
Electron accumulation in the case of a positively charged beam (Coulomb)

→ E-cloud effect more relevant for positively charged beams (LHC)

Ionization of the restgas

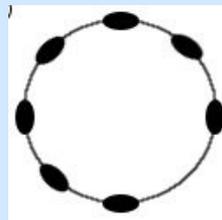


Conventional Ion Instability:

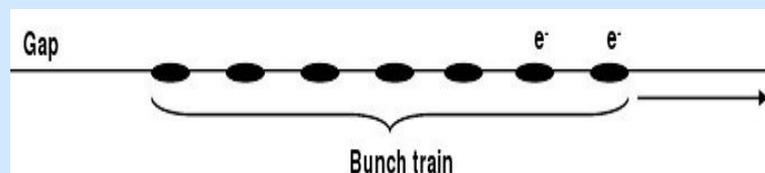


No gap in e-beam
Ions trapped
Ion lifetime $\gg 1$ turn

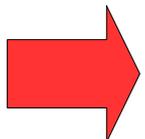
Fast Ion Instability:



Gap in e-beam
Ions not trapped
Ion lifetime < 1 turn



Head-Tail effect (train or bunches)
→ Can occur in rings & linacs
→ Depends on the vacuum specifications



Fast Ion Instability could be also relevant for CLIC
→ Vacuum pressure low enough, so that the instability doesn't occur

Particle Beam:

Beam = several **bunches**

Bunch = many **particles**

each particle is represented by a position in phase space $(x_i, x_i', y_i, y_i', E_i, z_i)$

Sliced Beam:

Beam = many **bunches**

Each bunch is cut into longitudinal **slices**

Each slice consists of one or more **macroparticles** and each macroparticle is represented by a position in phase space

$$(x_i, x_i', y_i, y_i', E_i, z_i)$$

Longitudinal position

Energy

and a **weight** w_i

The weight of the macroparticles is proportional to the number of particles in the slice → longitudinal bunch distribution

Different energy of macroparticle → energy spread of the beam

Sliced beam model



longitudinal profile of the CLIC main beam

